Assessment of the International Terrestrial Reference System 2014 realizations by Precise Orbit Determination of SLR Satellites

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Outline

⇨ Three new International Terrestrial Reference System (ITRS) realizations based on data from 1980 to 2015 became recently available:

- DTRF2014 (Seitz et al., 2016),
- ITRF2014 (Altamimi et al., 2016),
- JTRF2014 (Abbondanza et al., 2016)

⇨ In this study, we assess them, as compared to SLRF2008 (Pavlis, 2009) that is based on satellite laser ranging (SLR) data of LAGEOS-1/2 and Etalon-1/2 from 1983.0 to 2009.0.

⇨ We perform precise orbit determination (POD) of 10 geodetic satellites: LAGEOS-1, LAGEOS-2, Etalon-1, Etalon-2, LARES, Larets, Ajisai, Starlette, Stella, and Jason-2 at the 24-year time interval (1993.0 – 2017.0) using SLR observations.

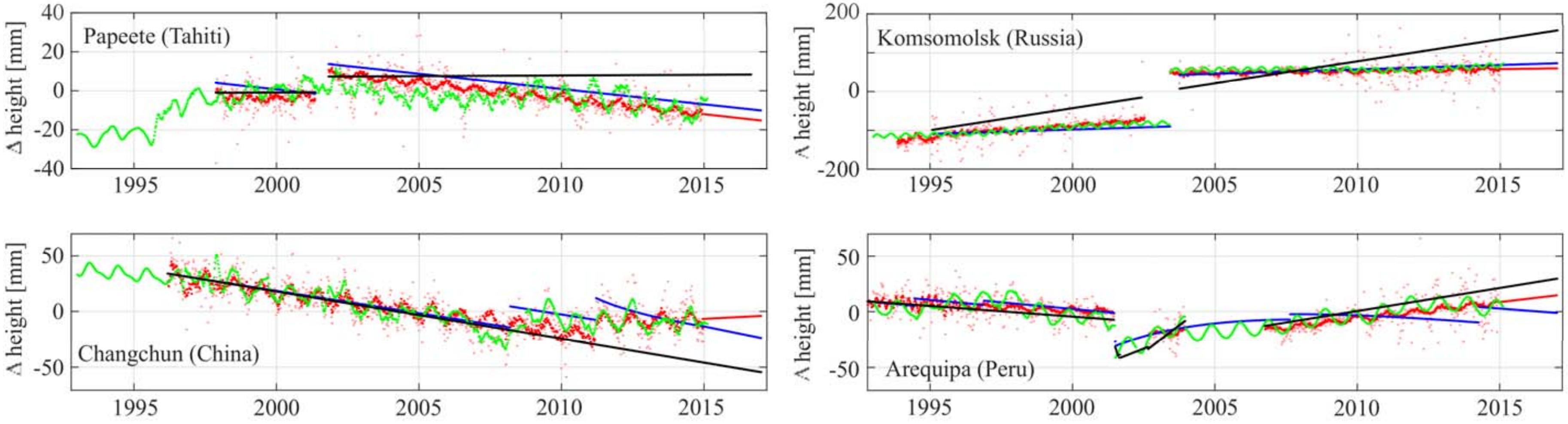
⇨ We use "DGFI Orbit and Geodetic parameter estimation Software (DOGS)“ for POD.

⇨ We investigate the impact on:
- station height time series,
- estimated pass-wise range biases,
- root- mean-square (RMS) and mean fits of SLR observations,
- Jason-2 radial and geographically correlated errors, as well as RMS and mean of the sea surface height crossover differences.

The main characteristics of the ITRF2014, DTRF2014 and JTRF2014

Solution	ITRF2014	DTRF2014	JTRF2014
Institute	IGN (Paris, France)	DGFI-TUM (Munich, Germany)	JPL (Pasadena, USA)
Software	CATREF	DOGS-CS	CATREF + KALMAN
Combination approach	Solution (parameter) level	Normal equation level	Solution (parameter) level
Station position	Position $\boldsymbol{X}_{\boldsymbol{ITRF}}(t_0)$ + velocity $\dot{\boldsymbol{X}}_{\boldsymbol{ITRF}}(t_0)$ + PSD model (for selected stations) + annual signals (on request)	Position $\boldsymbol{X}_{\boldsymbol{DTRF}}(t_0)$ + velocity $\dot{\boldsymbol{X}}_{\boldsymbol{DTRF}}(t_0)$ + non-tidal loading (NTL) models + SLR origin (Ori) + residual station motions (Res)	Weekly positions $\widetilde{\boldsymbol{X}}_{\boldsymbol{JTRF}}(t_i)$

Impact of the ITRS realizations on SLR station height time series

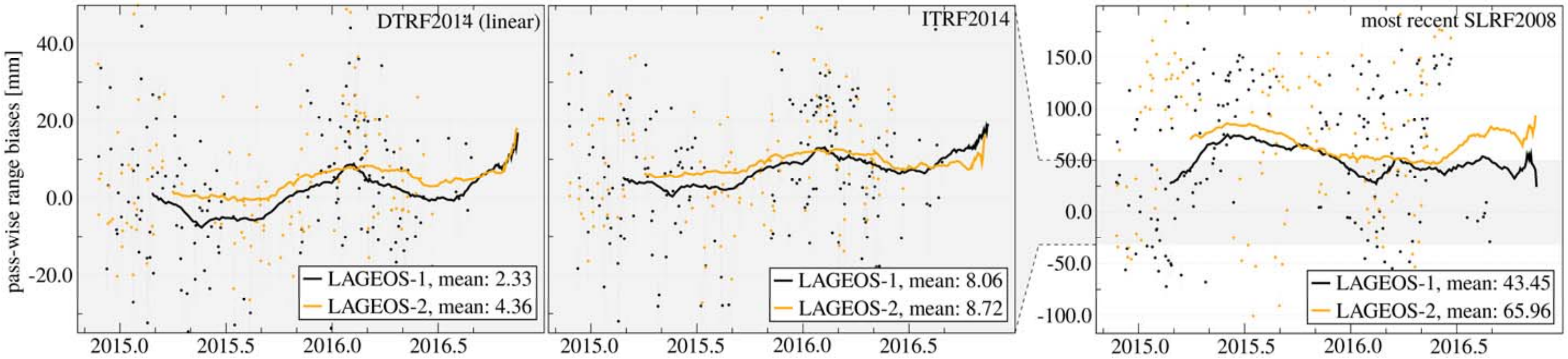


⇒ Height time series (in mm: common mean subtracted) of four ILRS stations for the **interpolation interval** (1993.0 - 2015.0) and the **extrapolation interval** (2015.0 - 2017.0) from three ITRS realizations: ITRF2014, DTRF2014+NTL, and JTRF2014, as compared to the most recent SLRF2008. Note: no seasonal, annual, or semi-annual corrections are applied within the extrapolation interval.

⇒ Height differences **by up to several cm** within the interpolation interval.

⇒ **Significant height discrepancies** accumulating with time in the extrapolation interval.

Impact of the ITRS realizations on the LAGEOS-1/2 estimated pass-wise range bias (mm) in 2015-2017: ILRS station Komsomolsk



⇒ The mean offset between the range biases obtained using various TRFs:

- ITRF2014 and DTRF2014: below 5 – 6 mm,
- SLRF2008 and ITRF2014: 35 – 57 mm,
- SLRF2008 and DTRF2014: 41 – 61 mm.

⇒ The mean values of the estimated range biases show that DTRF2014 performs better than ITRF2014, and SLRF2008 performs worse than both.

Orbit analysis approach

⇨ Up-to-date models based mainly on the IERS Conventions (2010)

⇨ Arc length: 7 days, but 3.5 days for Jason-2

⇨ Estimated parameters at each orbital arc:
- six Keplerian elements,
- one solar radiation pressure coefficient,
- Earth albedo and infrared radiation pressure coefficient,
- atmosphere drag coefficients: 12 h step for LEO satellites and none for HEO satellites,
- empirical accelerations: transversal and normal once-per-revolution cosine and sine terms (once per arc for LEO) and transversal terms (once per day for HEO).

⇨ Corrections in the JTRF2014:
- SLR station Concepcion (CDDIS SOD 74057903) excluded after 27 February 2010 - no jump caused by Maule earthquake (Mw = 8:8) is provided in the JTRF2014,
- SLR station Zimmerwald (CDDIS SOD 78106801): solution A (DOMES number 14001S001) is used before 30 April 1995 and solution B (DOMES number 14001S007) after this date.

Impact of the ITRS realizations on SLR RMS fits (cm)

Time span 1993.0-2015.0	LA-1	LA-2	Etalon-1	Etalon-2	LARES	Larets	Ajisai	Starlette	Stella	Jason-2
SLRF2008	1.72	1.72	2.59	2.52	3.07	4.34	3.81	3.59	4.08	2.42
ITRF2014	1.63	1.62	2.56	2.48	2.85	4.30	3.77	3.27	4.07	2.28
DTRF2014	1.62	1.62	2.54	2.48	2.83	4.30	3.70	3.16	4.05	2.24
DTRF2014 +NTL	1.47	1.48	2.53	2.47	2.82	4.21	3.65	3.11	3.35	2.24
JTRF2014	1.55	1.57	2.49	2.44	2.83	4.20	3.64	3.17	3.32	2.20
Time span 2015.0-2017.0										
SLRF2008	2.31	2.35	2.92	3.18	3.50	5.73	3.85	3.96	5.06	
ITRF2014	1.48	1.62	2.49	2.86	3.20	5.73	3.42	3.65	4.74	
DTRF2014	1.41	1.52	2.44	2.82	3.19	5.73	3.31	3.64	4.74	

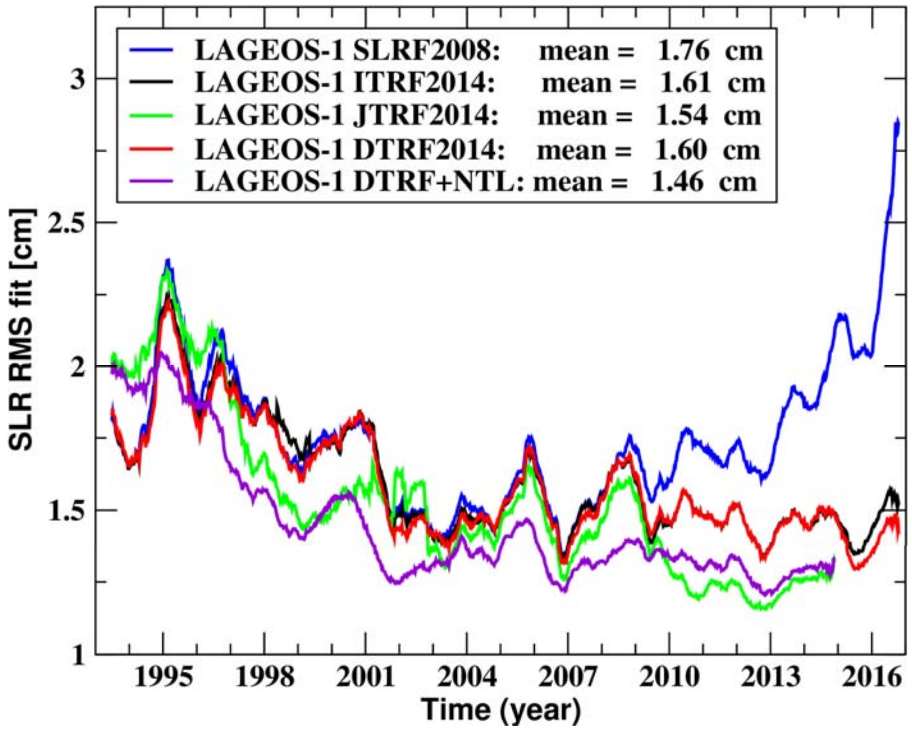
⇒ The smallest SLR RMS fits (marked in green) are obtained using JTRF2014 and DTRF2014+NTL for the interpolation period and using DTRF2014 for the extrapolation period for the most satellites.

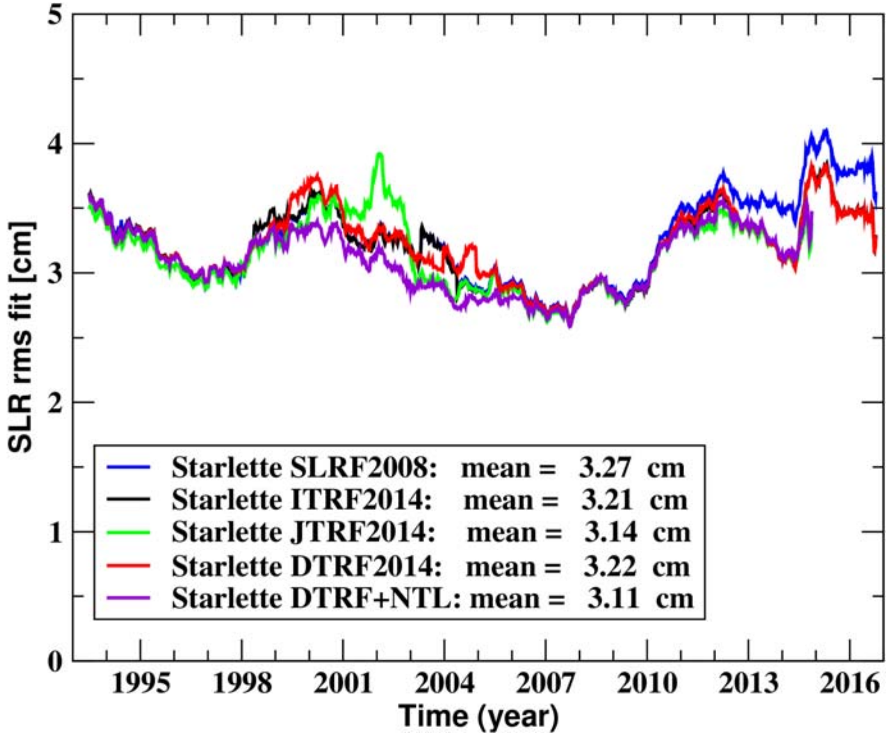
Impact of the ITRS realizations on SLR mean fits (cm)

Time span 1993.0-2015.0	LA-1	LA-2	Etalon-1	Etalon-2	LARES	Larets	Ajisai	Starlette	Stella	Jason-2
SLRF2008	0.10	0.18	0.18	0.21	0.11	0.26	1.31	0.10	0.00	0.06
ITRF2014	0.12	0.19	0.19	0.22	0.05	0.25	1.33	0.12	0.03	0.08
DTRF2014	0.03	0.08	0.12	0.15	-0.15	0.07	1.16	-0.05	-0.13	-0.04
DTRF2014 +NTL	-0.02	0.03	0.12	0.16	-0.13	0.07	1.16	-0.05	-0.14	-0.04
JTRF2014	-0.03	0.02	0.09	0.13	-0.13	0.07	1.16	-0.04	-0.10	-0.04
Time span 2015.0-2017.0										
SLRF2008	0.20	0.41	0.38	0.40	0.24	0.21	1.69	0.33	0.22	
ITRF2014	0.24	0.38	0.32	0.32	0.19	0.19	1.54	0.21	0.14	
DTRF2014	0.00	0.11	0.20	0.19	-0.01	0.02	1.35	0.02	-0.06	

⇒ The smallest SLR absolute mean fits (marked in green) are obtained using JTRF2014, DTRF2014 and DTRF2014+NTL for the interpolation period and using DTRF2014 for the extrapolation period for the most satellites.

50-week running averages of the SLR RMS fits derived using various ITRS realizations: case LAGEOS-1 and Starlette

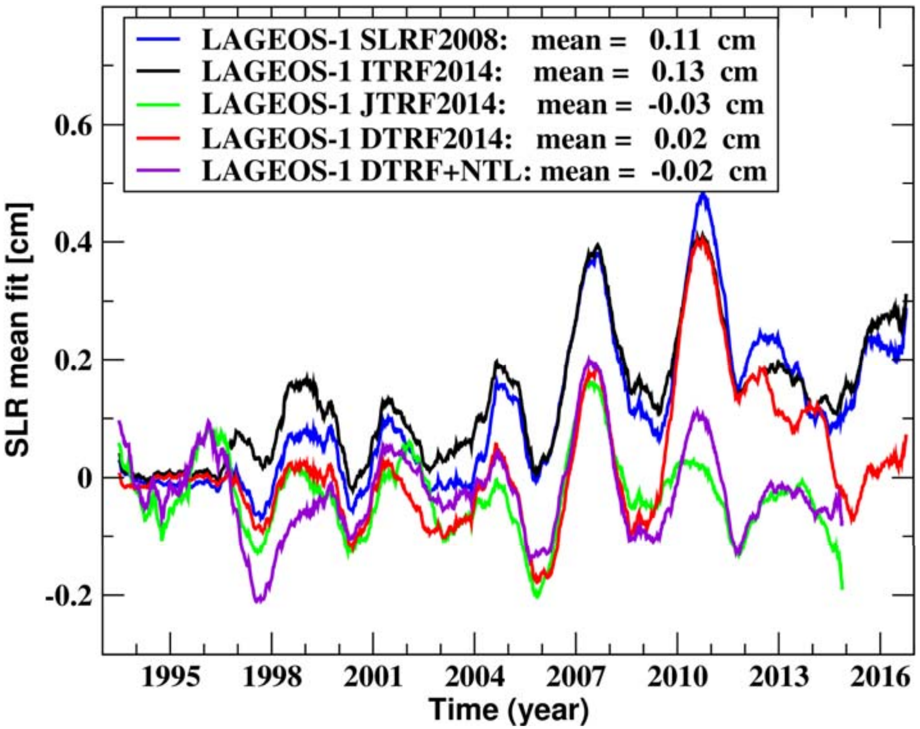


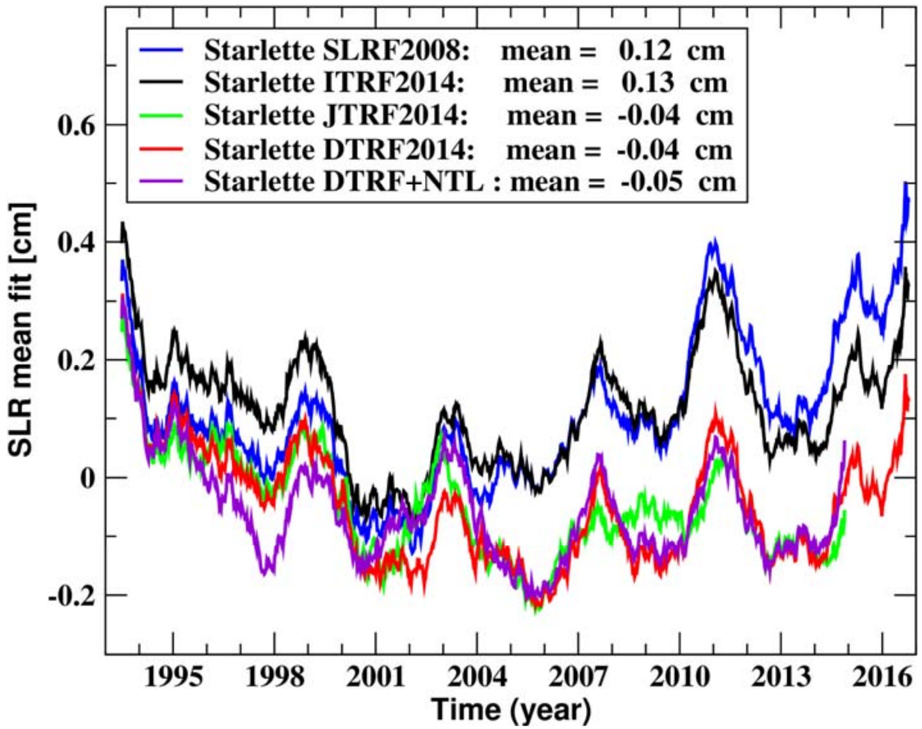


⇒ The smallest RMS fits are obtained using DTRF+NTL, followed by JTRF2014.

⇒ SLRF2008, on the contrary, shows starting from 2009 increasing with time RMS fits.

50-week running averages of the SLR mean fits derived using various ITRS realizations: case LAGEOS-1 and Starlette

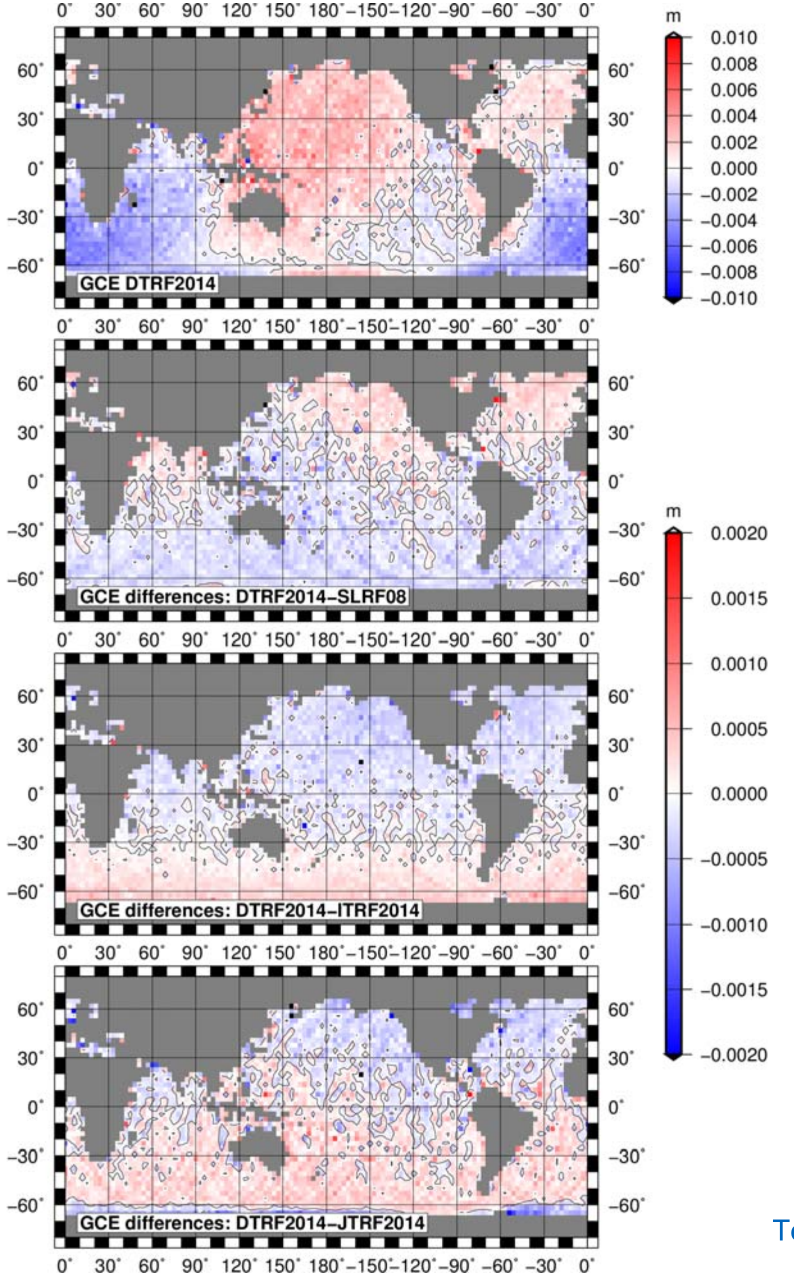




⇒ The DTRF2014, DTRF2014+NTL and JTRF2014 provide the smallest absolute mean SLR fits: 0.2-0.3 mm for LAGEOS-1 and 0.4-0.5 mm for Starlette.

⇒ SLRF2008 and ITRF2014 provide larger absolute mean SLR fits: 1.1-1.3 mm for both satellites.

Jason-2 geographically correlated mean SSH errors



10-day single satellite SSH crossover differences (SXO) for Jason-2 orbits based on various ITRS realizations:

ITRS realization	SXO mean [mm]	SXO std [mm]	Difference w.r.t. SLRF2008 mean [mm]	Difference w.r.t. SLRF2008 std [mm]
SLRF2008	1.00	59.52	---	---
ITRF2014	0.80	59.46	–0.2	–0.1
DTRF2014	0.68	59.40	–0.3	–0.1
DTRF2014 +NTL	0.64	59.38	–0.4	–0.1
JTRF2014	0.62	59.16	–0.4	–0.4

⇒ JTRF2014 provides the largest improvement of the SXO standard deviation.

⇒ JTRF2014 and DTRF2014+NTL give the smallest (best) SXO mean among the ITRS realizations tested.

Recommendation for the OSTST

JTRF2014 and **DTRF2014** with non-tidal loading corrections show the best performance among the ITRS realizations for the satellites tested and are recommended to use for POD.

Manuscript submitted to „IEEE Transactions on Geoscience and Remote Sensing“: “Evaluation of DTRF2014, ITRF2014 and JTRF2014 by precise orbit determination of SLR satellites” by Rudenko et al. (in review)

Summary

Precise orbit determination of 10 geodetic satellites using SLR observations at the time interval from 1993.0 to 2017.0 allows us to make the following conclusions:

⇒ Heights of some SLR stations computed using ITRS2014 realizations show differences by **up to several cm** within the interpolation interval **and even more significant discrepancies** accumulating with time in the extrapolation interval.

⇒ The smallest RMS fits of SLR observations are obtained using **JTRF2014** and **DTRF2014+NTL** for the interpolation period and using **DTRF2014** for the extrapolation period for the most of satellites.

⇒ The smallest absolute mean fits of SLR observations are obtained using **JTRF2014, DTRF2014 and DTRF2014+NTL** for the interpolation period and using **DTRF2014** for the extrapolation period for the most of satellites. ITRF2014 shows a trend in the mean fits of SLR observations since 2004.

⇒ As expected, SLRF2008 shows RMS and mean fits of observations that increase with time starting from 2009.

⇒ Analysis of the Jason-2 single-satellite altimetry crossover differences indicates that **JTRF2014** provides the major improvement of the SXO standard deviation, and **JTRF2014 and DTRF2014+NTL** give the smallest (best) SXO mean among the ITRS realizations tested.

⇒ From our analysis, we conclude that **JTRF2014** and **DTRF2014** with non-tidal loading corrections show the best performance among the ITRS realizations for the satellites tested and are recommended to use for POD.

References

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Acknowledgements

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